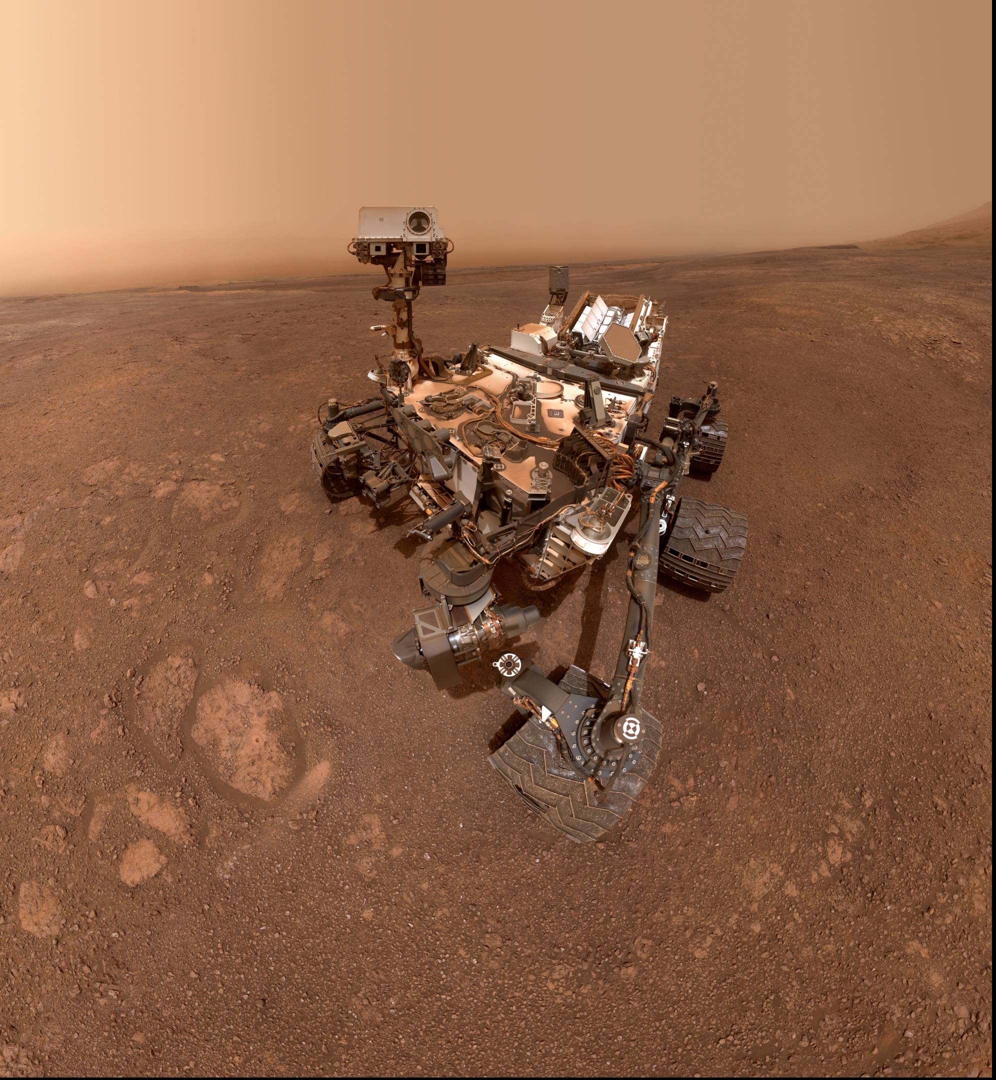

MSL Relay Coordination and Tactical Planning in the Era of InSight, MAVEN, and TGO

Authors: Rachael Collins, Pegah Pashai, Emma Young, Christopher Bennett, Sharon Laubach, Steven Thomas
Presented by: Pegah Pashai

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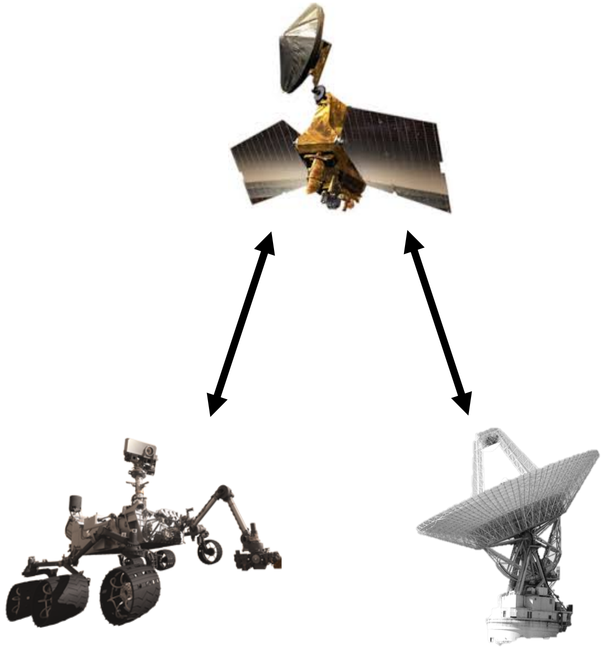
Overview

- Background
- InSight's Arrival at Mars
- Introduction of MAVEN and TGO Relay: Benefits and Challenges
- Redesigning Relay Planning
- New Overflight Selection Requirements & Approach
- Impacts
- Summary

Background

- Mars surface operations requires knowledge of latest rover state to inform planning for the next Martian day (sol)
- Timely and routine data return is critical for nominal rover operations
- Data needed to enable next sol planning is “decisional”
- Critical science activities are scheduled between uplink of rover commands and decisional downlink pass
- Mars Science Laboratory (MSL) relies on Mars Relay Network orbiters to achieve downlink timeliness and throughput required for operations
- Relay opportunities and performance are tightly coupled to MSL operations efficiency and science return

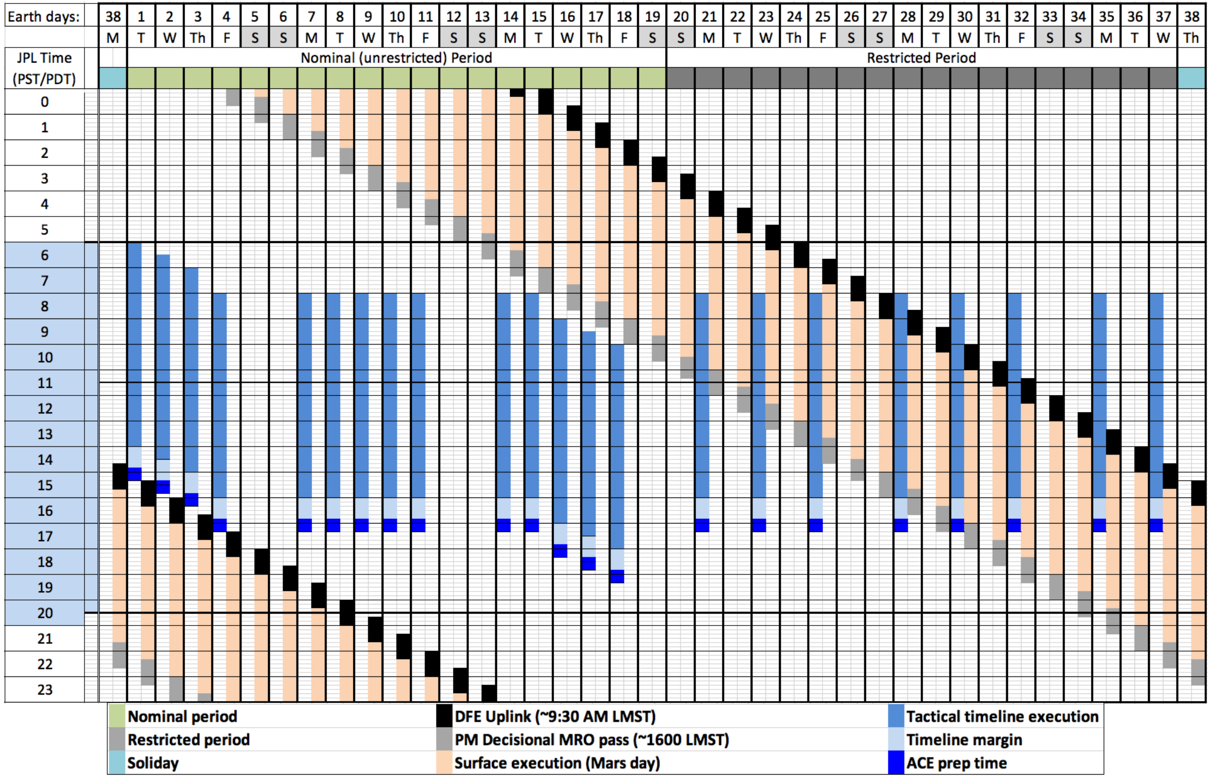


Planning Timeline

- Earth-Mars phasing results a daily ~40 minute shift of downlink and uplink windows relative to Earth time
- Time between receipt of latest rover telemetry and deadline to radiate planned commands and sequences bounds the planning timeline
- MSL planning occurs between 06:00 to 19:30 PT in order to maintain sustainable operations (human factors)
- Operations efficiency* is the ratio between the number of unrestricted or "nominal" planning days to the number of Martian days (sols)
- Greater operations efficiency yields more interaction with rover by operations team and therefore more science

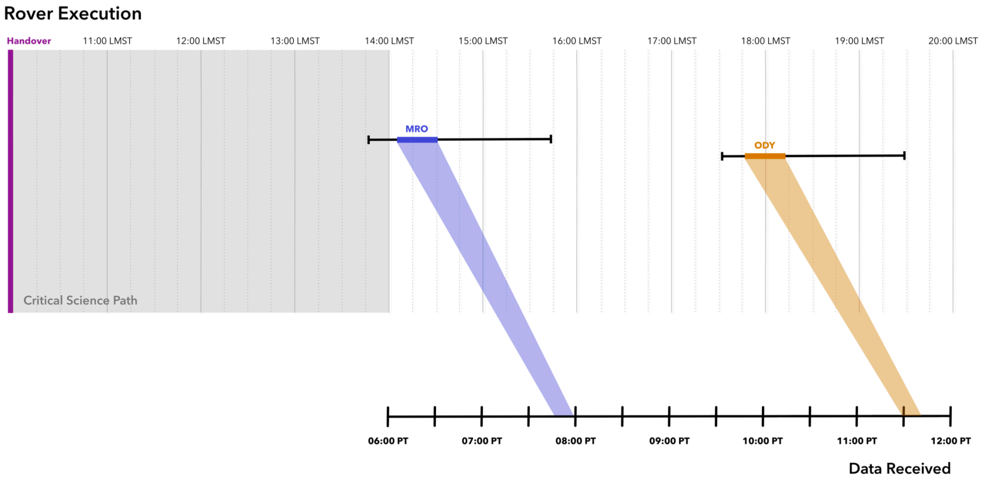
Sharon Laubach, "Calculation of Operations Efficiency Factors for Mars Surface Missions"

Planning Timeline



Previous Relay Planning Paradigm

- MSL's primary relay assets were sun-synchronous orbiters Mars Odyssey (ODY) and Mars Reconaissance Orbiter (MRO)
  - Overflight timing was temporally consistent
  - Overflights did not interfere with critical science
  - Overflights did not interfere with each other
- Time between uplink window and decisional pass is the Critical Science Path (CSP)
- Initial MSL mission design relied on these factors to ensure sufficient decisional data return for next sol planning
- Consistency lent itself to simple relay planning
  - All usable overflights were scheduled for relay



InSight's Arrival at Mars

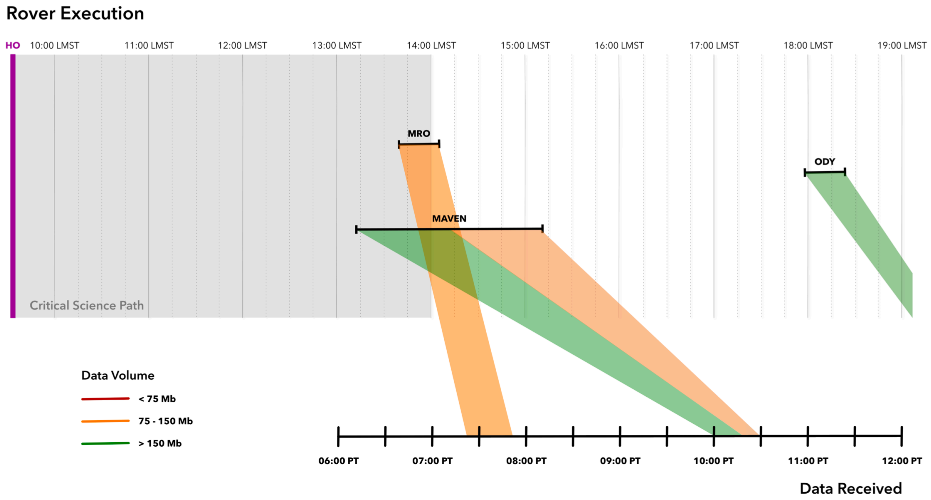
- InSight arrived at Mars in November 2018 in close proximity (600km) to MSL
- Overflights must now be distributed between the two missions, resulting in fewer relay opportunities for MSL
- MSL and InSight missions came to an agreement on the allocation of orbiters and overflights
  - Dependent on InSight's operations timeline during deployment phase and MSL's decisional data needs post-deployment
- Integration of Mars Atmosphere and Volatile Evolution (MAVEN) and Trace Gas Orbiter (TGO) orbiters as nominal relay assets help alleviate the impact of reduced relay/downlink, but not without introducing additional challenges
- Two landers in close proximity also introduced the need to consider interference ("crosstalk") as well as the potential to split single overflight opportunities

Benefits and Challenges of MAVEN and TGO Relay

- Both orbiters exercise great relay performance and increase overall data return
- MAVEN and TGO occupy non-sun-synchronous orbits that precess
  - Overflight timing is *not* temporally consistent but “walks” sol-to-sol
  - This also exacerbates crosstalk concerns
- Usability is directly affected as overflight timing shifts and either is too early (conflicts with CSP) or becomes too late to be used decisionally
- MAVEN also occupies a highly elliptical orbit (apoapsis: ~6,000km)
  - View periods range from ~10 minutes to 2-3 hours (max. overflight duration is 30 min.)
  - Data return varies widely seasonally
- MAVEN is significantly impacted by atmospheric drag (periapsis: ~150km)
  - Data return predictions are impacted as planned overflight geometries shift

Redesigning Relay Planning

- New paradigm requires deconflicting and down-selecting from available overflights
- How do we choose the "best" overflight? How do we maintain operational efficiency?
- Overflight selection criteria was established based on the following key metrics:
  - Data return
  - Latency (data arrival timeliness)
  - Local Mean Solar Time (LMST)
- Initial focus on decisional and total data return



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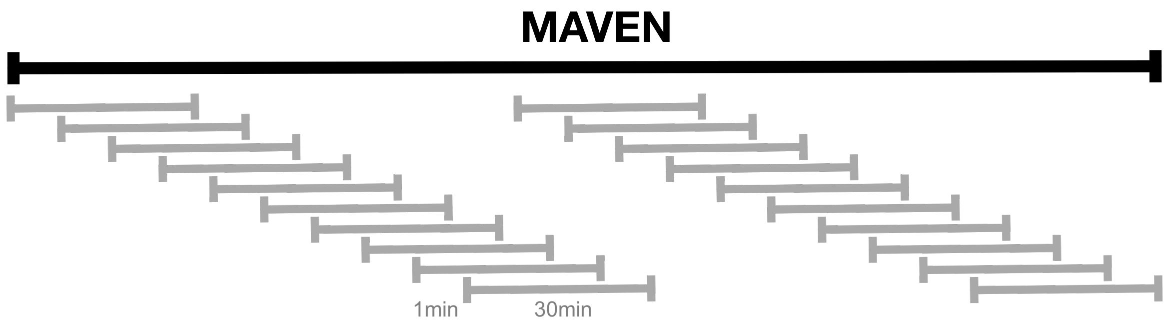
Implementation of MAVEN Sliding Windows

- MAVEN view periods are >30 minutes in duration
  - 30 minutes is the maximum allowable overflight duration (thermal constraints)
  - To allow selection of the “best” 30 minutes of a MAVEN view period, individual 30 minute segments are created and assessed individually



Overflight Selection Requirements

- Vehicle Health & Safety / Mission Robustness
- Anomaly Recovery
- Mission Efficiency/Return
- Special Cases

*New effort in 2019 not captured in paper

Overflight Selection Requirements

- Vehicle Health & Safety / Mission Robustness
  - Schedule “Critical pass” downlinks after critical rover activities
  - Maintain orbiter diversity
- Anomaly Recovery
  - Consider MSL Safe Mode windows
- Mission Efficiency/Return
  - Optimize decisional pass selection
  - Maximize total data return
- Special Cases
  - Allow customized scheduling for demo purposes, etc.

Overflight Selection Approach

1. Critical Pass Selection
   - >50Mbit, >2pm LMST
   - Earliest Earth Receive Time (ERT) (±2 hours)
2. Decisional Pass Selection
   - Prioritize selection based on key metrics using decisional “filter table”
3. Remaining Pass Selection
   - Maximize total data return
   - Consider MSL Safe Mode windows
   - Maintain orbiter diversity

Priority	>= LMST	>= DV (Mb)	Tactical Shift Start (hours from 08:00PT)	Tiebreaker

*Approach and values have matured since paper

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Priority	>= LMST	>= DV (Mb)	Tactical Shift Start (hours from 08:00PT)	Tiebreaker
1	16:00	250	1.5	Orbiter

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Priority	>= LMST	>= DV (Mb)	Tactical Shift Start (hours from 08:00PT)	Tiebreaker
1	16:00	250	1.5	Orbiter
2	16:00	120	1.5	Data Volume

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1	16:00	250	1.5	Orbiter
2	16:00	120	1.5	Data Volume
3	15:15	250	1.5	Orbiter

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Overflight Selection Approach

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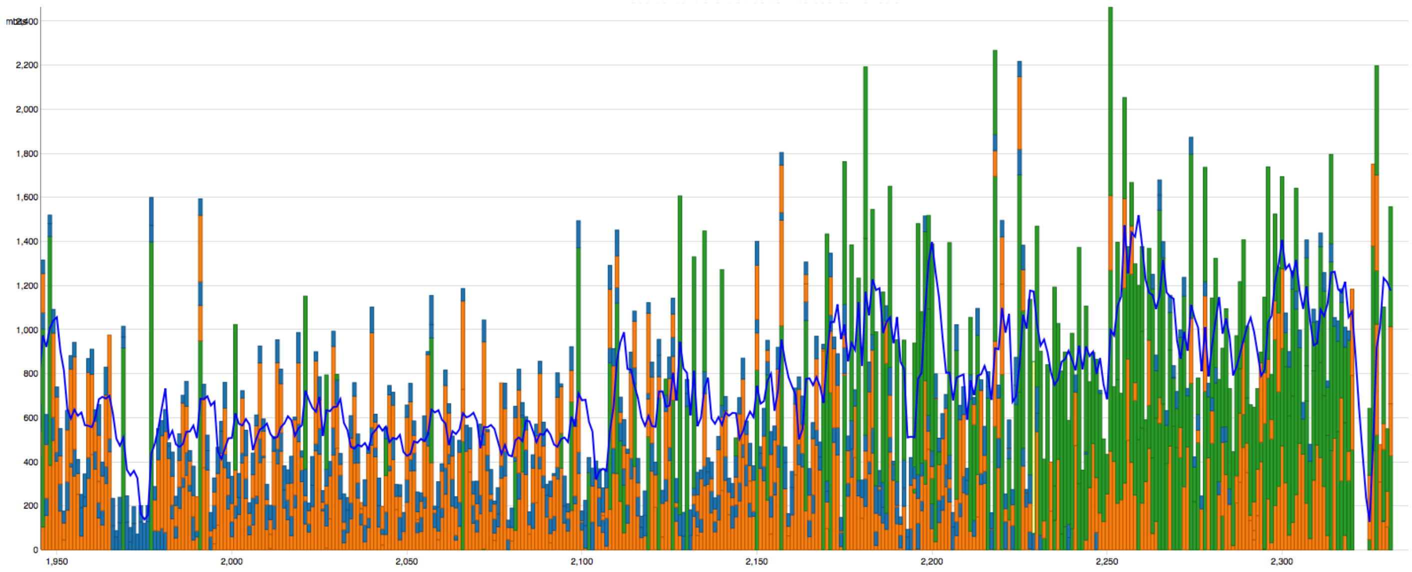
1	16:00	250	1.5	Orbiter
2	16:00	120	1.5	Data Volume
3	15:15	250	1.5	Orbiter
4	15:15	120	1.5	Data Volume
5	16:00	80	1.5	Data Volume
6	15:15	80	1.5	Data Volume
7	14:30	80	1.5	Data Volume
8	16:00	50	1.5	Data Volume
9	15:15	50	1.5	Data Volume
10	14:30	50	1.5	Data Volume
11	14:30	80	3.5	Shift Start
12	14:30	50	3.5	Shift Start
13	12:30	80	3.5	CSP
14	12:30	25	3.5	CSP

*Approach and values have matured since paper

Impacts of Relay Planning Redesign

- Overall data return increase



Impacts of Relay Planning Redesign

- Automation of overflight selection process; removes the “human in the loop”
  - Preserves (and enhances) mission efficiency with increasing problem scope
- Well-defined rules to prioritize overflights based on key metrics of interest and competing constraints
  - Metrics: data return, latency, overflight timing
  - Constraints: InSight coordination, non-sun-synchronous orbiters, MAVEN orbit, human factors
- Transparent selection criteria which can be easily adapted per evolving mission requirements and desires
- Groundwork for a mission-independent, unified overflight selection framework
  - Could enable federated processes to be combined into a single architecture
- **“Smart” relay planning using modern systems engineering principles**

Summary

- InSight's landing at Mars in 2018 necessitated a redesign of MSL relay planning to not only adapt to fewer relay opportunities, but also to integrate MAVEN and TGO orbiters into nominal relay operations
- In doing so, MSL laid out the requirements necessary for preserving mission return and robustness
- MSL is maintaining historical operations efficiency despite sharing relay opportunities with InSight as well as:
  - Shift from simple and predictable relay planning to less consistent planning start times due to non-sun-synchronous orbiters
  - New non-sun-synchronous orbiters create complexities in operations but improve overall operations efficiency and increase data return
- Constraints, challenges, and solutions captured could inform design and foundation of future relay networks at other planetary bodies

References

- Add paper references to presentation?

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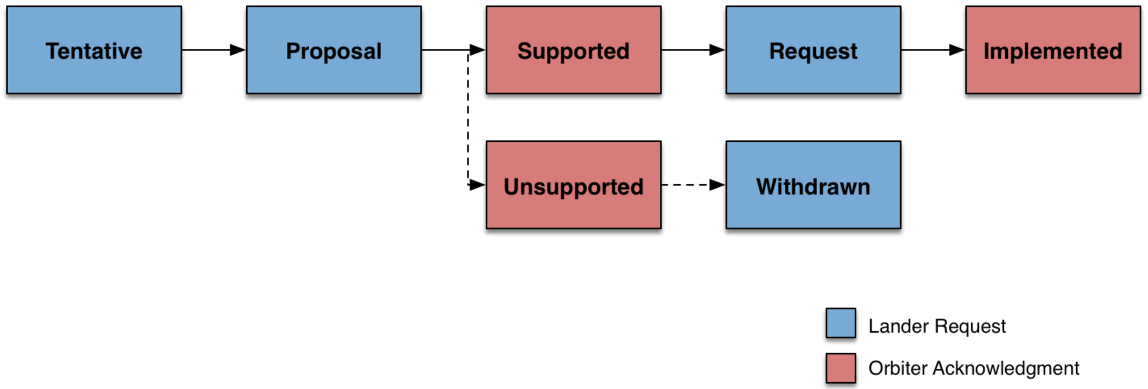
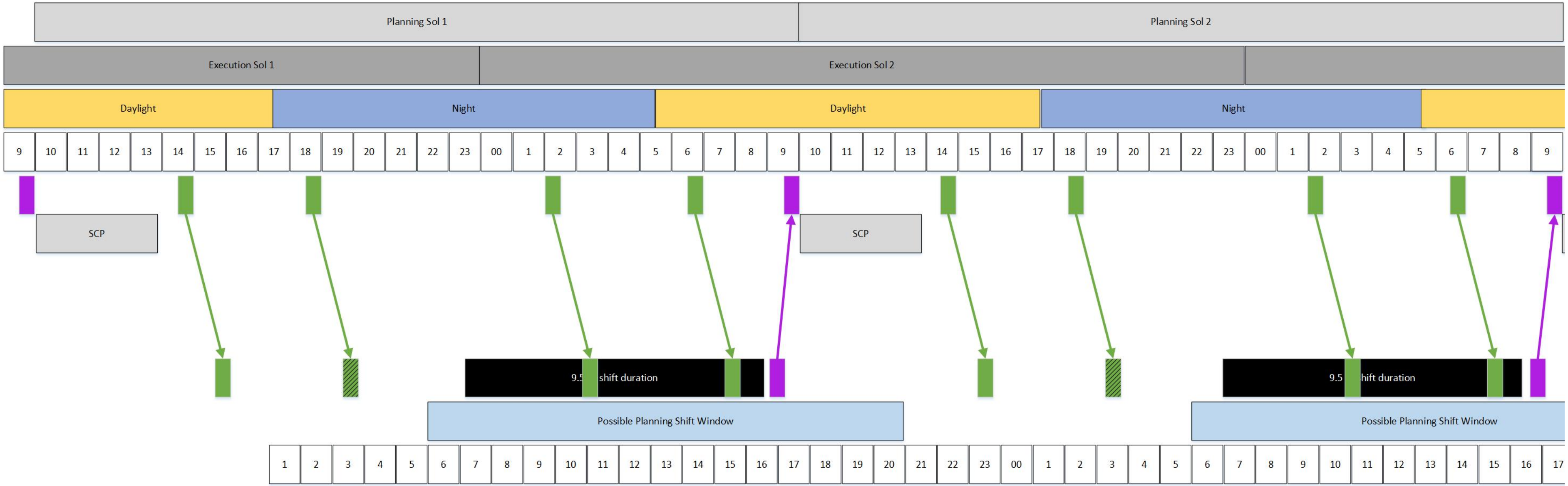
Backup

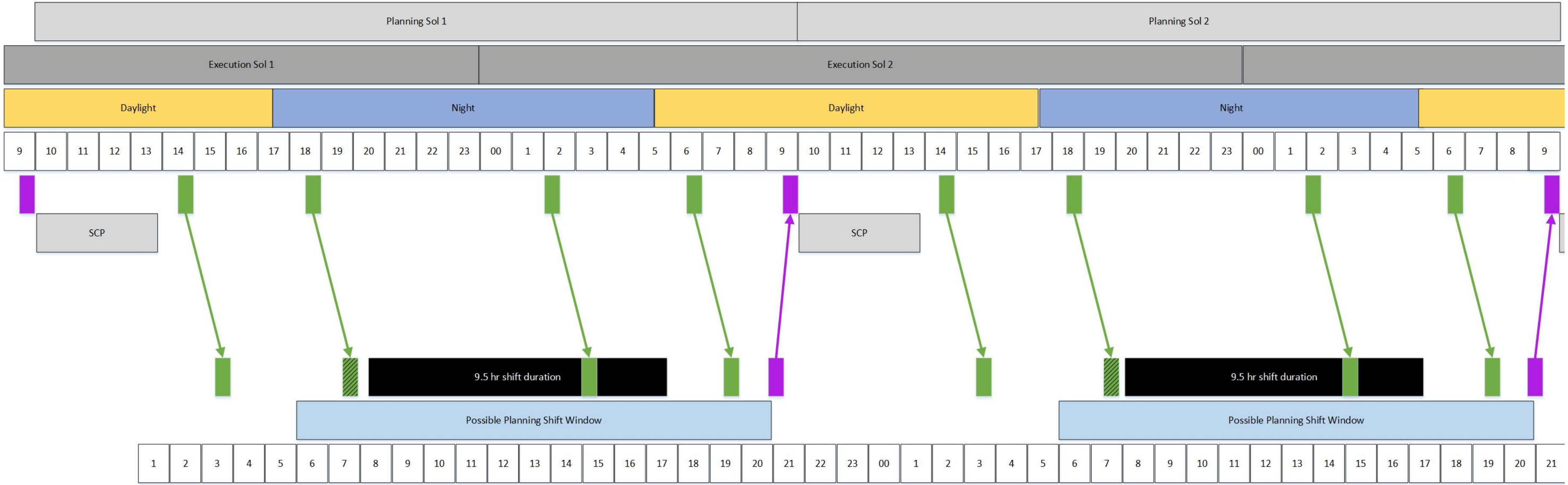
Mars Relay Planning Overview



Early Slide

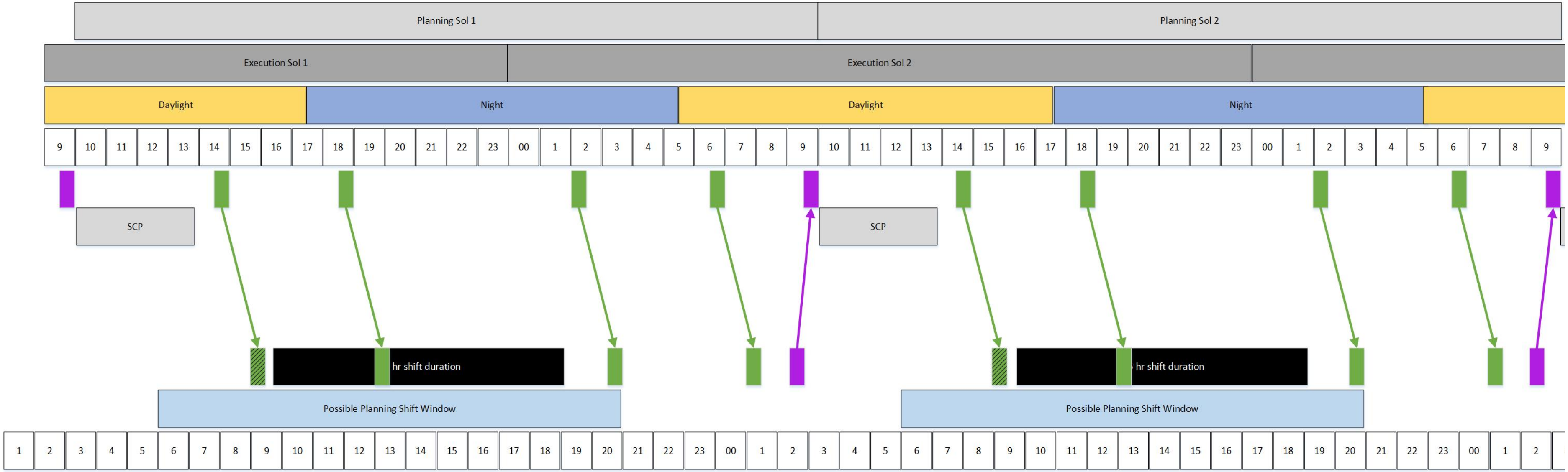

Planning Sol 1
Planning Sol 2
Execution Sol 1
Execution Sol 2
Daylight
Night
Daylight
Night
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9
SCP
SCP
9.5
shift duration
9.5
hift duration
Possible Planning Shift Window
Possible Planning Shift Window
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Nominal



Planning Sol 1
Planning Sol 2
Execution Sol 1
Execution Sol 2
Daylight
Night
Daylight
Night
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9
SCP
SCP
9.5 hr shift duration
9.5 hr shift duration
Possible Planning Shift Window
Possible Planning Shift Window
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Late Slide



Planning Sol 1
Planning Sol 2
Execution Sol 1
Execution Sol 2
Daylight
Night
Daylight
Night
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9
SCP
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hr shift duration
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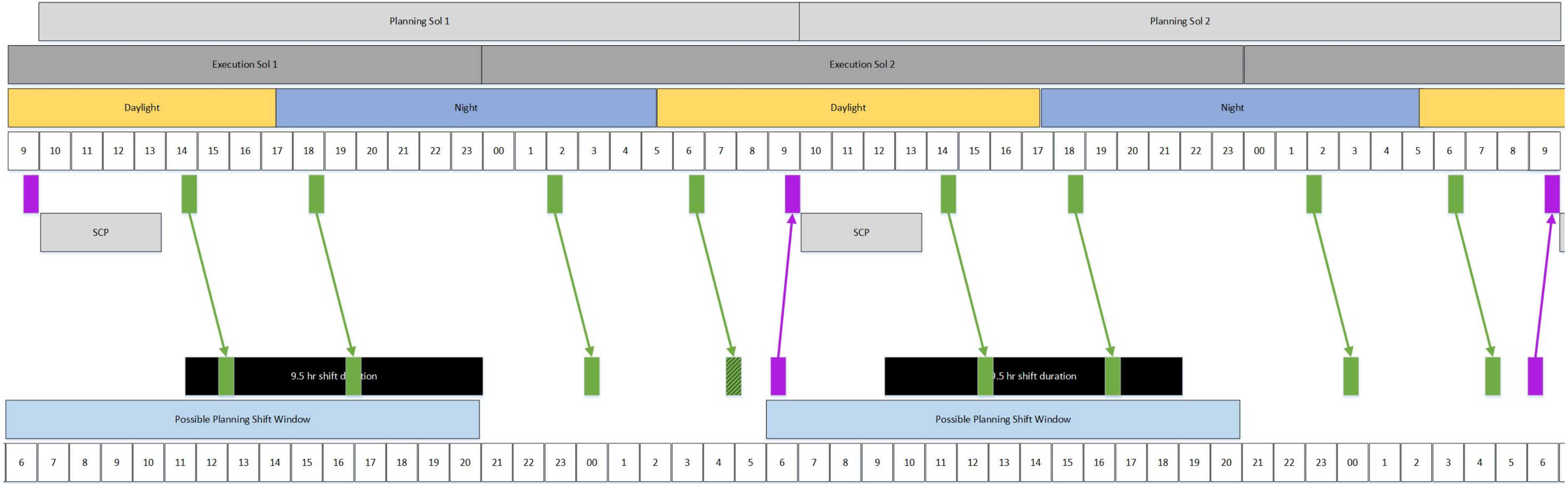
Possible Planning Shift Window
Possible Planning Shift Window
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 1 2

Restricted


Planning Sol 1
Planning Sol 2
Execution Sol 1
Execution Sol 2
Daylight
Night
Daylight
Night
SCP
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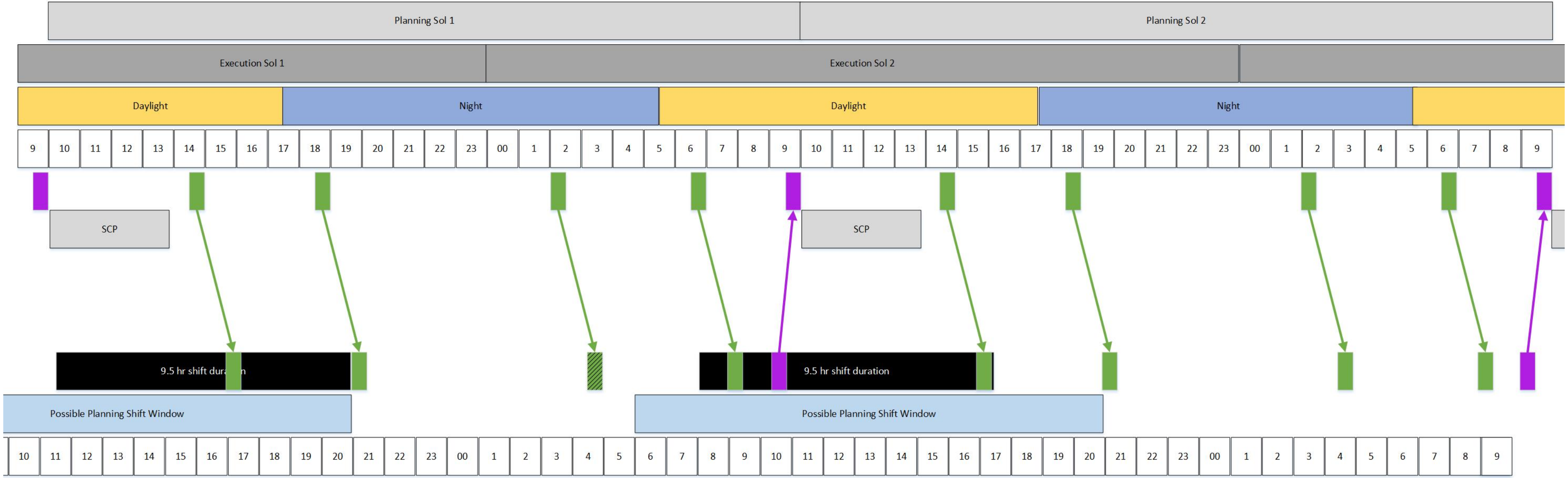
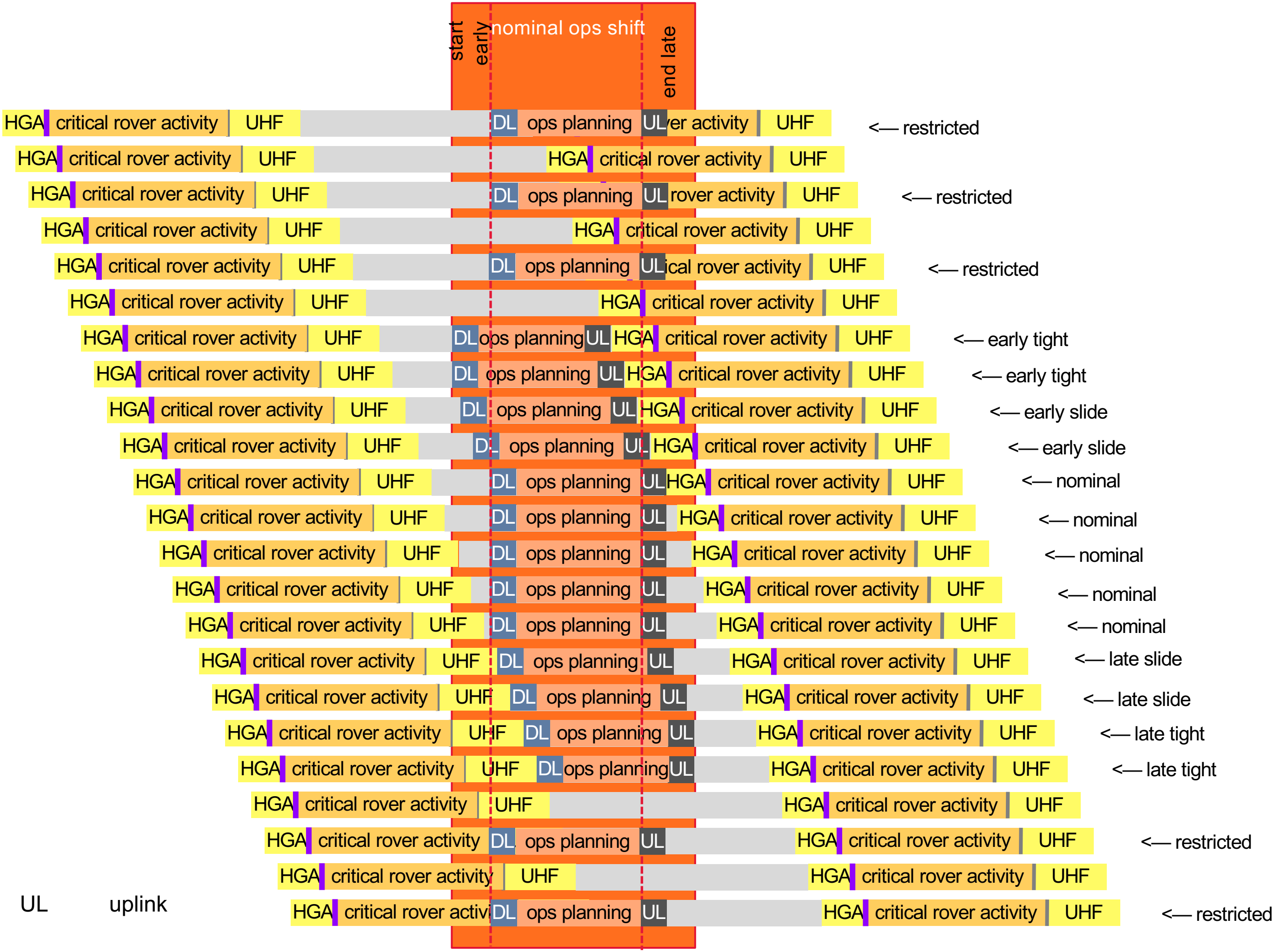
9.5 hr shift d
tion
.5 hr shift duration
Possible Planning Shift Window
Possible Planning Shift Window

Deep Restricted




start early
nominal ops shift
end late
HGA
critical rover activity
UHF
DL
ops planning
UL
<— restricted
<— early tight
<— early slide
<— nominal
<— late slide
<— late tight

UL uplink